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Analysis of Seating and Restraint Limitations Restricting Total Body Weight for Aircrew and Passengers on U.S. Army Helicopters

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Aviation Life Support Equipment (ALSE) and crashworthy seating protect the crew and passengers in military aircraft. If the user exceeds the design weight or size range for personal protective equipment, it may not function properly. The distribution and changes in body weight and relevant anthropometric measures were evaluated for soldier and aviator groups. Current ALSE and aircraft restraints were surveyed to determine the largest available sizes. Each aircraft seat was evaluated to determine the crash strength and maximum allowable weight for a given crash pulse.

The 99th percentile male soldier and aviator weigh 237.5 and 228.2 pounds, respectively. The average body weight increases with age for the male aviator population. The largest available flight suit (size 48L), SRU-21/P survival vest, and webbing restraints accommodate a 47-inch waist circumference.

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Introduction

Army aviation provides a flexible and mobile means to project combat power. Every soldier has specific tasks that must be completed to ensure survival and victory on the battlefield. The considerable expense required to train and equip our soldiers makes each a valuable asset. The injury or loss of any soldier represents a significant loss in the battlefield commander's warfighting capacity.

Aviation Life Support Equipment (ALSE) and crashworthy components of new military aircraft have been developed to protect the crew and passengers. However, for these components to work correctly, each user must be within the physical design parameters for the particular component. If an aircrew member or passenger exceeds the design weight and/or size range for the personal protective equipment, the equipment may not function properly. Malfunction of personal protective equipment can permit excess morbidity and/or mortality.

Background

The weight of a U.S. Army servicemember is regulated in accordance with Army Regulation (AR) 600-9, The Army weight control program, and AR 40-501, Standards of medical fitness (1989). The standard states a male soldier can weigh from a minimum of 100 pounds to a maximum of 250 pounds or up to 26 percent body fat (age 40 and over). A female soldier can weigh from a minimum of 90 pounds to a maximum of 227 pounds or up to 34 percent body fat (age 40 and over). The distribution of body weight for male and female soldiers has been studied by Gordon et al. (1989).

Initial flight physicals for pilots also require applicants to fall between several minimum and maximum anthropometric measures to ensure that they are able to reach the controls in Army aircraft. (Schopper, 1986) These measures and limits are summarized in Table 1.

Table 1.

Anthropometric limits for disqualification on Class 1 and 1A flight physicals.

Anthropometric measure	Disqualified if ...
Total arm reach	Less than 164 cm
Crotch height	Less than 75 cm
Sitting height	Greater than 102 cm

Limits on anthropometric measures have resulted in a pilot population with a different body weight distribution from the Army in general.

Most Army aircraft systems and ALSE were designed to accommodate the 5 percent to 95 percent male aviator in relevant anthropometric measures. Today, these measures may be invalid due to aviator selection bias, aging of the pilot population, and an increased number of female pilots. For example, a comparison of body weight for the male and female pilot population groups is presented in Figure 1. As a result of these changes, current ALSE may not fit some of the aircrew at the extremes of anthropometric measures and crashworthy seating may not function properly for an individual with a body weight above or below the design weight.

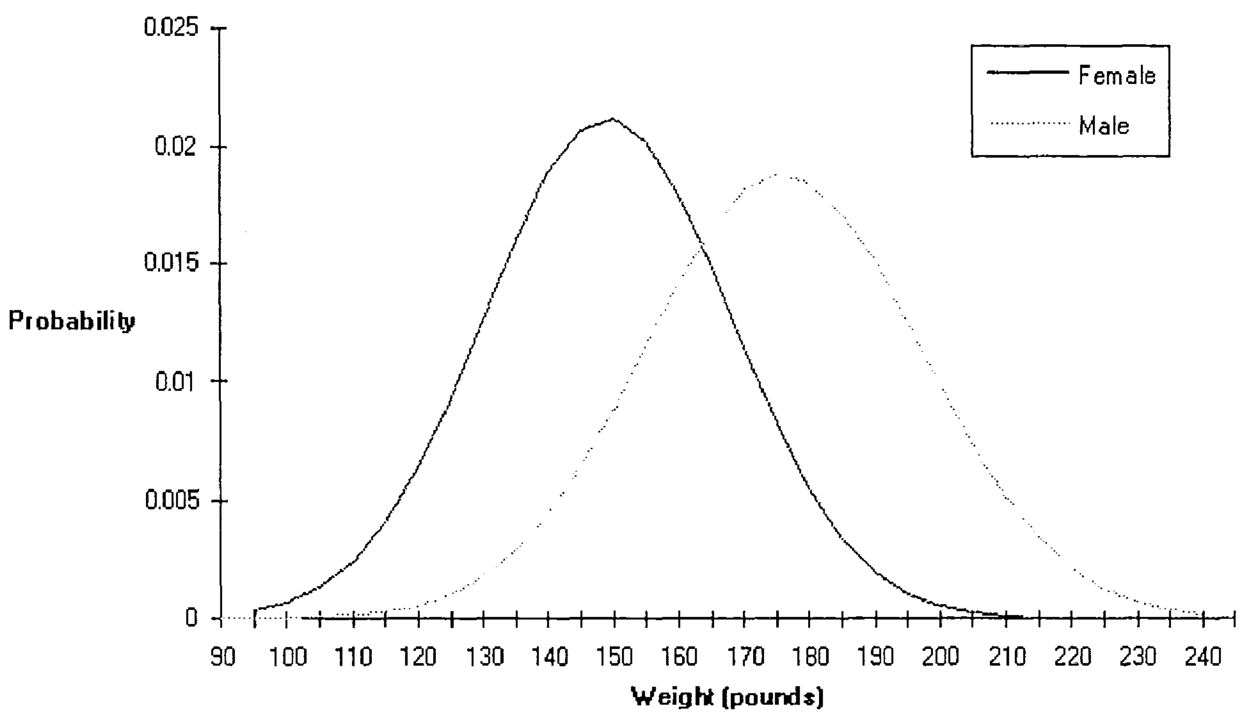

Figure 1. Distribution of body weights among male and female pilots (Donelson and Gordon, 1991).

This study evaluates body weight distributions for the soldier and aviator populations, currently available ALSE, and design weight limits for aircraft seating. These factors are analyzed to determine body weight design limits and effects of restricting total body weight for passengers and crew in U.S. Army aircraft.

Materials and methods

Soldier and aviator weight distributions

The 1988 anthropometric survey of U.S. Army personnel (Gordon et al., 1989) was used to obtain representative distributions of total body weight for soldiers and aircrew. A separate study of the Aviation Epidemiology Data Registry (AEDR) was used to detect the trend in weight change for aircrew since 1988 and the differences in body weight among active duty, National Guard, and Army Reserve aviators (Shannon, Bruckart, and Mason, 1993).

Survey of aviation life support equipment and restraints

The available sizes of personal aviation life support equipment were surveyed. The largest size of each item was examined to determine if persons with a large body weight would have difficulty donning, doffing, or wearing the equipment. The length of the restraint webbing was measured in several aircraft to determine available webbing to accommodate individuals with a large abdominal girth.

Survey of aircraft seats and maximum weight calculations

The design strength and static strength for troop and crew seats for each U.S. Army aircraft was determined from the engineering design specifications and prior testing. This included both rigid and energy-absorbing (crashworthy) crew and troop seats. The strength of each seat was divided by the impact load factor (Table 6) to obtain the maximum allowable seat weight using the method specified in the Aircraft crash survival design guide (Zimmermann and Merritt, 1989). The weight of the seat and aviator clothing was subtracted from the maximum allowable seat weight to obtain the calculated maximum nude weight for the seat occupant. The clothing and equipment weights were determined by weighing representative equipment. As specified in the design guide, the maximum nude weight is increased by 25 percent for vertical (downward) impacts to account for the weight of the legs supported by the floor in these crashes.

Results

Soldier and aviator weight distributions

The weight distribution for male and female U.S. Army soldier and aviator groups are presented in Table 2.

Table 2.

Distribution of body weight (pounds) among male and female soldiers and aviators. (Gordon et al., 1989; Donelson and Gordon, 1991)

	Male soldiers	Female soldiers	Male aviators	Female aviators
Mean	173.0	136.7	175.9	144.1
Standard deviation	24.5	18.4	21.2	18.8
Minimum	104.9	91.0	125.1	102.1
Maximum	281.8	213.1	249.9	212.7
1st %	121.9	99.7	132.5	105.2
5th %	135.8	109.4	143.7	115.8
50th %	171.3	135.0	174.4	142.4
95th %	216.2	169.7	213.8	177.6
99th %	237.5	186.7	228.2	196.2

Study of the AEDR (Shannon, Bruckart, and Mason, 1993) shows the average age of the aviator population has increased since 1988. Along with the increase in age, there has been a corresponding increase in average body weight.

Aviation life support equipment and restraints

The weight of standard items worn by U.S. Army pilots is shown in Table 3. The largest U.S. Army flight suit (size 48L) will accommodate a waist circumference up to 47 inches. The personal survival vest is adjustable and also accommodates a waist circumference of 47 inches. The UH-60 pilot seat will accommodate an abdominal girth of 48 inches within the seat pan and restraint webbing. The UH-60 crew seat and troop seat will accommodate 54 and 48 inches abdominal girth, respectively. The pilot seat in the AH-64 will accommodate a 48-inch abdominal girth. The distribution of waist circumference for the Army in general and aviator populations are shown in Table 4 (Gordon et al., 1989, and Donelson and Gordon, 1991).

Table 3.

Weight of standard items worn by U.S. Army pilots and crew.

Item	Weight (pounds)
Flight helmet, SPH-4B	2.9
Flight suit (Nomex coveralls)	3.1
Boots	4.0
Gloves	0.3
Flashlight	0.1
Survival vest, SRU-21/P with contents	7.3
Total	17.7

Table 4.

Distribution of waist circumference (inches) among male and female soldiers and aviators.
(Gordon et al., 1989; Donelson and Gordon, 1991)

	Male soldiers	Female soldiers	Male aviators	Female aviators
Mean	33.95	31.18	34.98	32.15
Standard deviation	3.40	3.26	2.99	3.53
Minimum	25.75	24.02	27.17	25.20
Maximum	46.65	43.62	46.85	43.27
1st %	27.42	25.36	28.85	25.96
5th %	28.84	26.60	30.16	27.13
50th %	33.68	30.75	34.94	31.73
95th %	40.00	37.26	39.96	38.66
99th %	42.39	40.40	41.59	41.21

Aircraft seats

The available data on the crash strength of crew and troop seats for Army aircraft are shown in Table 5. The minimum load factor, from MIL-S-58095A, for static seat tests is shown in Table 6. The calculated maximum soldier weight for each aircraft seat is shown in Table 7.

Discussion

The anthropometric data for the Army in general and aviator groups show that male soldiers are 25 percent heavier on average than female soldiers. Likewise, average body weight increases with age in the male aviator group.

The restraint webbing will accommodate at least 48 inches waist circumference in the UH-60 pilot seat and the AH-64 pilot seat. This is greater than the maximum measured waist circumference (46.85 in) from the Natick anthropometry studies. The largest flight suit and survival vest also will accommodate a soldier with this abdominal girth (up to 47 in).

Only the pilot seats in the UH-60 and AH-64 meet the static strength required by MIL-S-58095A. Most of the other seats fail first with the 35 G load along the X (forward) axis. These older aircraft were designed and fielded with less stringent crash performance designs. In fact, most of these airframes will not maintain structural integrity and livable space when the floor sustains a 35 G crash load. Future aircraft seats are expected to meet or exceed these performance requirements. Therefore, the recommended maximum weight should be based on a seat and aircraft which is expected to maintain a survivable space and environment under a 95th percentile crash loading as stated in the Aircraft crash survival design guide (Zimmermann and Merritt, 1989). The maximum nude weight for the UH-60 and AH-64 pilot should be 238.8 pounds. Pilots that weigh more than 238.8 pounds may experience structural failure of the seat during a mishap with survivable X-axis loads in the UH-60 and AH-64 aircraft.

None of the troop or crew seats match the crash performance of the AH-64 or UH-60 pilot seats. Arguably, most soldier passengers spend only a small amount of time in the aircraft and are exposed to only an infrequent risk from these seats. Crew members that must perform frequent flights are at the greatest risk. In this case, there is no clear milestone on which to base a recommended maximum weight for crew or passengers. Everyone is at risk of seat failure in a crash with significant impact forces.

Table 5.

Seat crash strength (pounds) under quasistatic load.

		Rotary-wing						Fixed-wing	
	Type seat	CH-47	UH-1	OH-58	OH-6	UH-60	AH-64	OV-1	C-12/ U-21
Seat weight (lbs)	Pilot	30	135	a	a	115	138	175	30
	Crew	10	12	a	a	18			20
	Troop	10	10	NA	NA	15			20
X-axis load (lbs)	Pilot	2760	6000	4200	3400	13002	13807	16480	2760
	Crew	3900	1680	3000	3000	6000[b]			2640
	Troop	2000	2000[c]	NA	NA	6000[b]			2640
Y-axis load (lbs)	Pilot	2760	3000	2100	1700	7430		8000	700
	Crew	2000	1680	2000	1700	3000[b]			700
	Troop	2770	2200[c]	NA	NA	3000[b]			700
Z-axis load (lbs)	Pilot	2760	2200[d]	2200[d]	2200[d]	2929[e]	3640[e]	5000	1200
	Crew	2200[f]	2200[f]	5000[d]	2200[d]	2929[e]			
	Troop	2200[f]	2200[f]	NA	NA	2929[e]			

[a] Seat is integral to aircraft structure
[b] Exact strength unknown since seats did not pass dynamic qualification tests
[c] Side facing troop seat
[d] Net cushion "bottoms out" on seat frame
[e] 12-inch stroke results in 14.5 G for 170.5-pound occupant
[f] Cloth seat rips apart

References: Aerojet-General, 1966; Department of Defense, 1957 and 1965; Desjardin et al., 1989; New, 1974; U.S. Army Research and Development Command, 1980; and U.S. Army Transportation Research Command, 1962

Table 6.

Load factors (G) for static seat tests (Department of Defense, 1986; Desjardins er al., 1989).

Loading direction	Pilot seats	Crew & troop seats
Forward (X)	35	30
Lateral (Y)	20	20
Downward (Z)	25	25

Table 7.

Maximum soldier weight (pounds) for aircraft seats.

Aircraft and seat	Seat weight	Strength	Load Factor (G_x)	Calculated maximum weight*
CH-47 pilot	30	2760	35	31.1
CH-47 crew	10	3900	30	102.3
CH-47 troop	10	2000	30	39.0
UH-1 pilot	135	6000	35	153.7**
UH-1 crew	12	1680	30	26.3
UH-1 troop	10	2000	30	39.0
OH-58 pilot	integral	4200	35	102.3
OH-6 pilot	integral	3400	35	79.4
UH-60 pilot	115	13002	35	238.8
UH-60 crew	18	6000	30	164.3
UH-60 troop	15	6000	30	167.3
AH-64 pilot	138	13807	35	238.8
OV-1 pilot	175	16480	35	278.1***
C-12/U-21 pilot	30	2760	35	31.1
C-12/U-21 crew	20	2640	30	50.3

*(strength/load factor) - (seat weight + 17.7 lbs equipment weight)

** maximum weight based on strength of floor-attached harness strength, seat weight disregarded.

*** based on seat crash strength, actual weight limited to 220 lbs for ejection capability.

Summary

More than 99 percent of Army soldiers and aviators weigh less than 240 pounds and have a waist circumference less than 42.5 inches. Male soldiers are on average 25 percent heavier than female soldiers and average body weight increases with age.

The current flight suit and survival vest will accommodate a waist circumference up to 47 inches. Restraint webbing in UH-60 and AH-64 aircraft should accommodate these individuals.

Pilot seats in the AH-64 and UH-60 are expected to accommodate a 238.8-pound individual with 17.7 additional pounds of clothing and equipment without failure during the static load tests. Seats and aircraft structure from older aircraft will not meet this performance.

Crew and troop seats in all aircraft will not meet the crash performance of the AH-64 and UH-60 pilot seats. All passengers in these seats are at risk of seat failure in severe crashes (greater than 35 G_x).

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